

## OUTPUT CHOKE FOR D.C. WELDER AND METHOD OF USING SAME

The present invention relates to an output choke for a D.C. arc welder and a method of  
controlling the inductance in the output circuit of a D.C. electric welder using such choke.

### BACKGROUND OF INVENTION

In D.C. electric arc welders, the output circuit normally includes a capacitor in parallel across the electrode and workpiece with a relatively small inductance for charging the capacitor as the rectifier or power supply provides D.C. current. This inductance removes the ripple from the welding current. In series with the arc gap of the welder there is provided a large choke capable of handling high currents over about 50 amperes and used to control current flow for stabilizing the arc. As the feeding speed of the electrode toward the workpiece and the length of the arc change, the welding current varies. In the past, the large output choke in series with the arc had a fixed air gap in the core to control the inductance at a fixed value as current changes. However, when the choke experienced high weld currents, the core saturated and reduced the inductance drastically. For this reason, the width of the air gap in the core was enlarged to provide constant inductance over the operating current range of the welder. The choke was selected for a particular operating current range. However, this range would vary for different welding operations. Thus, the air gap of the choke was selected for the majority of welding operations. In a standard choke, a small air gap provided high inductance, but would saturate at relatively low currents. To increase the current capacity of the choke, the air gap was enlarged to reduce the amount of inductance for a particular size of the choke. For these reasons, the choke was made quite large with large wires to carry the weld current and

a large cross sectioned core to prevent saturation. The gap was large to accommodate a wide range of welding currents. Such chokes were expensive and drastically increased the weight of the welder. Further, the choke produced a constant inductance until the saturation point or knee, even though ideal arc welding is realized with an inductance that is inversely proportional to the weld current. To alleviate these problems, it has been suggested that the air gap could include two or three different widths. This suggestion produced a high inductance until the small air gap saturated. Thereafter, a lower inductance would be realized until the larger air gap saturated. By using this concept of two, or possibly three, stepped air gaps, the size of the choke could be reduced and the range of current controlled by the choke could be increased. Further, the relationship of current to inductance was inverse. The concept of using a stepped air gap in the core of the output choke allowed a smaller choke; however, one or more inflection points existed. When the feed speed of the electrode or arc length changed to operate in the area of the inflection points, the D.C. welder would oscillate about the saturation or inflection points causing unstable operation. A standard swinging choke was not the solution because the weld current varied too much to operate on the saturation knee. In addition, such swinging chokes were for small current applications.

The use of a fixed output choke for a D.C. arc welder is now standard. Such choke is large and the operating point is in the linear portion of the inductance preventing drastic reductions in the output inductance of the welder. Such choke is expensive and heavy. By the procedure of having a stepped air gap, the size of the choke could be reduced and the current operating range increased; however, the inflection point at the saturation of one gap, made the welder less robust and susceptible to oscillation at certain arc lengths and feed speeds. Consequently, this suggested modification was not commercially acceptable.

## THE INVENTION

The present invention relates to an output choke for a D.C. arc welder which solved the problems of weight, cost and welding inconsistencies experienced by a large choke having a fixed air gap or a smaller choke having a stepped air gap. In accordance with the invention, the output choke for the D.C. arc welder comprises a high permeability core with an area having a cross sectional shape with two spaced edges and an air gap wherein the air gap has a gradually converging width for at least a portion of the distance between the two edges. Thus, the air gap gradually increases from the edges. In the preferred embodiment, the air gap is a diamond shape, gradually increasing from the edges to the center portion of the core. This diamond core technology for the output choke of a D.C. welder produces an inductance in the output circuit which gradually varies over the current range in an inverse relationship with the weld current. As the welding current increases, the inductance decreases in a continuous manner without any discontinuity or steps. Thus, the weld current is never at a saturation point for the output choke or operating on the saturation knee. There is no oscillation of the power to the weld. This invention produces a robust welder which can handle changes and up to 5-10 volts with arc length changes without causing instability of the arc. Thus, the choke provides current control over a wide range of weld currents without oscillating or without the need for a large output choke.

In accordance with another aspect of the present invention the output choke includes a high permeability core with an air gap defined by first and second pole pieces terminating in first and second surfaces facing each other. Each of these surfaces has two spaced apart edges with an intermediate area with the facing surfaces converging from the intermediate area toward the respective edges of the surfaces to generate a specific cross sectional shape for the

air gap. This cross sectional shape is preferably a diamond; however, it may be an oval or other curvilinear shape so long as there is gradual changes in the inductance with changes in weld current. In the preferred diamond shape air gap, the intermediate area is in the center of the pole pieces; however, the intermediate area may be closer to one edge of the facing surfaces.

5 This provides a non-equilateral diamond. In accordance with another aspect of the invention, the gap may have a shape which converges from one edge of the facing surfaces toward the other edge of the facing surfaces. This provides an air gap having the shape of a triangle. All of these configurations result in a choke where the inductance gradually changes with the output current of the welder without saturation between adjacent areas causing inflection points that can result in hunting or oscillation of the welder at certain wire speeds and arc lengths.

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Another aspect of the present invention is the provision of a method of controlling the inductance in the output circuit of a D.C. electric arc welder operated over a given current range to weld by passing a weld current in the gap between an electrode and a workpiece. This method comprises: providing an inductor with a generally constant inductance over the current range for charging a capacitor connected in parallel with the welding gap or arc; providing an output choke with an inductance gradually varying over the current range; and, connecting the choke in series with the gap or arc and between the arc and the capacitor. In this method, the inductance varies in a generally straight line inversely proportional to the weld current so that as current increases the inductance gradually decreases along a generally straight line. This is an optimum relationship for arc welding. Generally straight includes concave or convex linear relationship so long as there is no inflection points along the curve as are caused by stepped air gaps.

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The present invention relates to an arc welder which requires a relatively large output choke. This field is distinguished from power supplies used for low power appliances, such as lights, sound or video equipment. Such miniature power supplies do not have the large currents or the large range of currents needed for arc welding. An arc welder involves currents exceeding 50 amperes. Indeed, the choke of the present invention is a choke that can handle currents of 100-500 amperes while still maintaining an unsaturated core. The invention handles at least about 100 amperes. This clearly distinguishes the output choke of the present invention from other inductors used in power supplies.

The present invention is directed to the arc welding field where the optimum operation involves an inverse relationship between the inductance and weld current. Small inductors are usually used where the optimum operating characteristic between current and inductance is linear. To provide operation in an inverse relationship between current and inductance, such small inductors are operated on the knee of the saturation curve. This provides an inductance that is maximum for small current and swings to a lower value as the current increases. Such inductors are referred to as "swinging reactors"; however, they operate over a relatively small current range at the knee of the magnetic saturation curve and normally are sized to handle small currents less than 10 amperes. Such small swinging reactor could not be successful for the output choke of a D.C. welder since the current range is quite large and the weld currents are extremely large, over about 50 amperes.

The primary object of the present invention is the provision of an output choke for a D.C. arc welder, which choke has a gradually varying inductance over a wide current range and is capable of handling currents exceeding about 50 amperes and normally in the range of 100-500 amperes.

Still a further object of the present invention is the provision of an output choke for a D.C. arc welder, as defined above, which choke produces no inflection points and does not cause the power supply to oscillate as the wire feed speed is changed or as the arc length is changed.

5            Still a further object of the present invention is the provision of an output choke for a D.C. arc welder, as defined above, which choke has no areas of non-linearity and can operate over a wide weld current range without saturation.

Yet another object of the present invention is the provision of an output choke for a D.C. arc welder which has a generally straight line relationship between current and inductance  
10 over a wide range of welding currents and the method of controlling the inductance in the output circuit of a D.C. electric arc welder using this choke.

Still a further object of the present invention is the provision of an output choke for a D.C. arc welder and method of using same, as defined above, which allows for high inductance at low wire feed speed and low inductance at high wire feed speeds without transition from one  
15 saturation curve to another saturation curve for the choke.

Another object of the present invention is the provision of an output choke for a D.C. arc welder which has a diamond shape air gap to control the current-inductance relationship.

These and other objects and advantages will become apparent from the following description taken together with the accompanying drawings.

**BRIEF DESCRIPTION OF DRAWINGS**

FIGURE 1 is a schematic wiring diagram of a D.C. arc welder having an output circuit using the present invention;

FIGURE 2 is a pictorial view showing schematically a standard, prior art output choke for a D.C. welder;

FIGURE 3 is a current-inductance graph showing the saturation curves for various air gaps used in the prior art choke schematically illustrated in FIGURE 2;

FIGURE 4 is a pictorial view showing schematically an output choke for a D.C. welder which has been suggested for correcting the problems of the prior art choke illustrated schematically in FIGURE 2;

FIGURE 5 is a current-inductance graph showing the saturation curve for the choke illustrated schematically in FIGURE 4;

FIGURE 6 is a pictorial view of an output choke for a D.C. welder constructed in accordance with the preferred embodiment of the present invention;

FIGURE 7 is a current-induction graph for the preferred embodiment of the present invention as illustrated in FIGURE 6;

FIGURES 8, 9 and 10 are partial views of the core and air gaps having shapes using the preferred embodiment of the present invention;

FIGURE 11 is a current-inductance graph similar to FIGURE 7 showing the operating curve for the embodiments of the invention shown in FIGURE 8-10;

FIGURES 12 and 13 are partial view of the core of the choke showing air gaps having shapes which are modifications of the preferred embodiments of the present invention as shown in FIGURES 8-10; and,

FIGURE 14 is a partial view of the core of an electrode constructed in accordance with the present invention wherein the preferred diamond air gap shape is obtained by two core pieces which touch each other and are affixed.

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## PREFERRED EMBODIMENTS

Referring now to the drawings, wherein the showings are for the purpose of illustrating preferred embodiments of the invention only and not for the purpose of limiting same, FIGURE 1 shows a D.C. electric arc welder 10 capable of creating a welding current of at least about 50 amperes and up to 200-1,000 amperes. Power source 12, shown as a single phase line voltage, is directed through transformer 14 to rectifier 16. Of course, the rectifier could be driven by a three phase power source to create a D.C. voltage. In accordance with standard practice, a capacitor 20 having a size of about 20 K-150 K micro farads is charged by inductor 22 having a size of approximately 20 mH. Rectifier 16 charges capacitor 20 through inductor 22, which inductor may be replaced by inductance of the transformer. Output voltage from rectifier 16 at terminals 24, 26 is the voltage across capacitor 20 that maintains a voltage across arc gap *a* between electrode 30 from a wire feeder 32 and workpiece 34. To maintain an even flow of current across arc *a*, a relatively large output choke 50 is provided in the output circuit between capacitor 20 and gap or arc *a*. The invention involves the construction and operation of current control output choke 50, as best shown in FIGURE 6. In the past, output choke was a large choke as schematically shown in FIGURE 2 wherein choke 100 has a high dependability core 102 with an air gap *g* defined between two facing surfaces 104, 106. The high currents demand large wires for winding 110. To obtain high inductance, the number of turns is high. To prevent saturation the cross section of core 102 is large. Thus, choke 100 is large, heavy and



expensive. By changing the width of gap  $g$  between surfaces 104, 106, core 102 is saturated by high weld currents in winding 110 by saturation curves, as shown in the graphs of FIGURE 3.

When air gap  $g$  is relatively small for a given choke, a high inductance is created; however, at low weld currents the core is saturated. This is shown in saturation curve 120. As the width of gap  $g$  is increased, the inductance is decreased and saturation current is increased. This relationship of an increased gap size is indicated by saturation curves 122, 124 and 126. Each of the saturation curves has saturation knees or points 120a, 122a, 124a and 126a, respectively.

When operating arc welder 10 with a fixed air gap, as shown in FIGURE 2, a saturation curve must be selected to accommodate the desired welding currents. To produce both a high inductance and a large current range, the windings 110 must be increased and the core size must be increased. This drastically increases the size and weight of the choke. By decreasing the weight and size of the choke the saturation curve has a reduced saturation current which causes erratic operation of the D.C. welder. In order to correct the problems associated with an output choke having a fixed gap for controlling the current in the output circuit of a D.C. arc welder, it has been suggested to use a choke as shown schematically in FIGURE 4. Choke 200 includes a high permeability core 202 having an air gap 210. In this choke, the air gap is stepped with a large gap 212 and a small gap 214 created by adding a small pole piece 216.

When currents exceeding 100-500 amperes are passed through winding 220, the inductance follows a two part saturation curve as shown in FIGURE 5. This non-linear curve includes a first portion 230 employed until gap 214 is saturated and then a second portion 232 employed until larger gap 212 is saturated. These two sections create an effective current-inductance relationship illustrated by dashed line 240. This inverse current-inductance is extremely beneficial in electric arc welding. The two part curve accommodates both low current and high

current operation. However, there is an abrupt saturation knee 232a causing an inflection point 242. As the arc welder operates along line 240, inflection point 242 causes oscillation as the wire feed speed is changed or the arc length or arc voltage is changed. Thus, there is a hunting action in the area of the inflection point 242 which reduces the effectiveness of the suggested stepped air gap approach shown schematically in FIGURE 4.

Choke 50 of FIGURE 1 incorporates the preferred embodiment of the present invention as illustrated in FIGURES 6-8. Core 50 of high permeability material has a cross section large enough to prevent saturation at over 50 amperes and preferably over 100-500 amperes. Facing surfaces 54, 56 of core 50 are between spaced edges 54a, 54b and 56a, 56b. The respective transversely spaced edges face each other and provide a relatively small air gap, if any. The center area 58 between surfaces 54, 56 constitutes a large air gap. This diamond shape air gap is between the spaced edges of faces 54, 56 and is defined by portions 54c, 54d of surface 54 and 56c, 56d of surface 56. These portions diverge together from a maximum air gap at apex 54e and apex 56e of the diamond shaped air gap. A winding 60, having a size to carry the weld current and a turn number to obtain the desired inductance, conducts the welding current around core 52. By using the diamond shaped air gap as shown in FIGURE 6, with the selected core size and turn number, current-inductance curve 70 in FIGURE 7 is obtained. Curve 70 represents an ideal current-inductance relationship for electric arc welding when the current progresses from 20 amperes to a high level exceeding about 200 amperes and often exceeding 500-1,000 amperes. As shown in FIGURE 8, the small air gap at edges 54a, 56a and 54b, 56b tends to saturate at low currents. As the current increases, the diamond shaped air gap in choke 50 cannot saturate. At high levels the choke attempts to saturate an extremely large air gap. As indicated by the arrows, the saturation of the core by flux through the diamond shaped air

gap would saturate the smaller gaps at position a, but not progressing upward from points b, c, d. The apex of the diamond shaped air gap is selected to prevent saturation even at maximum weld current. Thus, there is a straight line relationship between current and inductance, which relationship is gradual and continuous by the use of the diamond shaped air gap.

Two other preferred embodiments using the diamond air gap concept are illustrated in FIGURES 9 and 10. In FIGURE 9, pole pieces 300, 302 of the core 52 have facing surfaces 304, 306 which are arcuate in shape to create an oval or elliptical air gap. This air gap includes small air gaps 310, 312 and a large center air gap at area 314. This preferred embodiment of the invention provides a linear curve 72 which is slightly concave, as shown schematically in FIGURE 11. A generally linear, but convex, curve 74 is created by the preferred embodiment of the invention illustrated generally in FIGURE 10 wherein core 52 includes pole pieces 320, 322 with facing surfaces 324, 326, respectively. These surfaces are curvilinear with small air gaps 330, 332 separated by an enlarged air gap at center portion 334. As can be seen, the preferred embodiments of the invention gradually change the width of the air gap from the center of the core to the outside edges of the core. The optimum application of the preferred embodiment is the diamond shaped air gap, as best shown in FIGURES 6 and 8. The oval air gap of FIGURE 9 and the curvilinear air gap of FIGURE 10 also provide a relatively straight, inversely proportional curve for the relationship between the current and inductance of the large current controlled by choke 50 used in a D.C. arc welder as illustrated in FIGURE 1.

In the preferred embodiments, the air gap is gradually converging and is symmetrical with respect to the core. It is possible to provide an asymmetrical air gap configuration as shown in FIGURES 12 and 13. In FIGURE 12, core 52a of choke 50 includes pole pieces 350,

352 with facing surfaces having converging portions 360, 362 and 364, 366. These portions define a large air gap area 338, which area is slightly offset from the center of the core. Another asymmetric air gap configuration is shown in FIGURE 13 wherein core 52b includes pole pieces 370, 372 with a angled surface 374 and a straight surface 376. The air gap shown in  
5 FIGURE 13 is also accomplished by forming pole piece 370 with a flat perpendicular surface, but tilting it with respect to pole piece 372. These structures produce an air gap with a small portion on the left and a large portion on the right. These two asymmetric air gaps produce better results than the stepped air gap 210 in FIGURE 4; however, they do not obtain the desirable effects shown in FIGURE 11 as accomplished by the symmetric air gap configurations shown in the preferred embodiments of FIGURES 8-10.

In practice, choke 50 has a core as illustrated in FIGURE 14. A diamond shaped symmetrical air gap 400 is provided between pole pieces 402, 404 with the abutting edge portions 406, 408 touching each other to define the intermediate air gap 400 with small gap portions 412, 414 gradually increasing to a large gap portion 414. Pole pieces 402, 404 are  
15 joined by a strap 420 using appropriate pins 422, 424. Air gap 400 is a diamond shaped air gap, which air gap is large at the apex or center and decreases toward both edges of the core. This diamond shaped air gap provides a generally straight line, inversely proportional relationship between current and inductance, which relationship is optimum for electric arc welding. A low permeability potting material can fill air gap 400 when the choke is packaged  
20 for use in the field.